Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October27-28, 2016

Value Tree Analysis Approach for Integrated Risk Informed Decision Making: Revision of Allowed Outage Time

Poorva P. Kaushik [a, b*], Sok Chul KIM [a*]
[a]*Korea Institute of Nuclear Safety, 62 Kwahak-ro, Yuseong, Daejeon, Korea, 34142*
[b]*Korea Advance Institute of Science and Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: poorvakaushik@gmail.com, jupiter@kins.re.kr*

1. Introduction

When a safety system is unavailable in the Nuclear Power Plants (NPPs), there is an increase in risk due to loss of its safety function. The Allowed Outage Time (AOT) of a safety system is the time period it may remain unavailable during power operation before a plant shutdown is required [1].

AOTs are usually determined using traditional deterministic approach. However, deterministic requirements are sometimes overestimated due to conservative analysis. Experience with plant operation has indicated that AOT may require revision to optimize the safe plant operation. Probabilistic analysis, on the other hand, uses realistic data in the risk models. However due to the inherent uncertainties in current risk models of NPPs, probabilistic approach is also not sufficient in itself.

Because of these inevitable gaps, making a decision only on the basis of deterministic analysis or probabilistic analysis can lead to un-optimized decisions. In addition to above, factors such as operating experience (OE), economic implications, and implementation complexity can also have a pivotal role in decision making. The decision making that involves the integration of such wide variety of information, insights and perspectives has been termed as Integrated Risk Informed Decision Making (IRIDM) [2].

The International Atomic Energy Agency (IAEA) has issued various technical documents related to IRIDM. The IAEA has outlined basic concepts for the use of risk information for decision making on NPP safety issues or regulatory activities [2]. It has also identified the basic framework of IRIDM and defined key inputs and principles of application of IRIDM [3].

IRIDM is a multi-attribute problem that considers a wide variety of inputs. Quantitative determination of the relative significance of these inputs and their impact on the final decision is difficult. Decision makers usually rely on their subjective decree to evaluate inputs and there is no strategy commonly applied to deal with this issue.

The purpose of regulatory decision making is to demonstrate the compliance with regulatory requirements. Regulatory decision making involves making an informed judgment. In the nuclear field, where risk is high, good reasoning is as important as the decision itself. Objectivity, transparency, and auditability are the foremost requirements for decisions on nuclear safety.

Mieczyslaw Borysiewicz et.al. have suggested the application of Value Tree Analysis (VTA) method in decision making as an improvement and further extension of framework recommended by IAEA [4]. VTA method replaces subjective judgments with value functions. The gains of application of the VTA methods within a multi-attribute decision making process is proven in varied industries. In the nuclear field, VTA was used successfully as one of the alternate methods for making decisions on the fuel conversion of the research reactor MARIA, Poland [4].

The present work proposes a new approach to IRIDM input evaluation for AOT optimization based on VTA methodology resulting in objective and transparent decision making.

2. Methods and Results

VTA method is used in multiple criteria decision making in which objectives/inputs are arranged hierarchically. Each objective is defined by attributes. Attributes are the measure of objectives. There can be several layers of objectives. Attributes are added to the lowest level of objectives to construct the value tree (see Fig 1). A value tree outlines the hierarchical relationship between multiple layers of objectives and attributes. [5]

2.1 Framework for proposed methodology

VTA methodology comprises of following steps:

I. Problem Structuring: The first step in problem structuring is clear definition of an issue for which decision has to be made and identification of various decision alternatives. The second step involves careful selection of inputs that need consideration for making the decision. These inputs will be specific to the issue under consideration. Various inputs that can be considered by regulatory body are deterministic insights, probabilistic insights, cost benefit, and OE. The third step is the identification of attributes (quantitative or qualitative) for respective inputs.

II. Preference Elicitation: The aim of this step is to measure and estimate the preferences for various inputs and attributes. This step is to set up the hierarchical order between various inputs and attributes to construct the value tree. It is carried out in following two steps:

   i. Weightage Elicitation: It involves assigning priorities among various inputs and their attributes. The relative importance for i^{th} input is given by W_i.The relative importance of the j^{th} attribute for the i^{th} input is given by A_{ij}.

   ii. Value elicitation: It describes the importance and desirability of achieving different performance levels of the given attribute for each alternative.

This is achieved through evaluation of consequence factor S_{ijk}. This factor describes how the implementation of the k^{th} option would affect the j^{th} attribute of i^{th} input.

III. Evaluation of decision options: Assuming the independence amongst the attributes and additive model, once the values of all attributes for each input are determined, best option with the highest score can be identified by using the following equation:

$$S_k = \sum_i Wi \sum_j Aij.Sijk \qquad (1)$$

2.2 Methods for Preference Elicitation

Various prioritization and value evaluation methods can be employed within the VTA method. Following are the commonly used methods:

2.2.1 Methods for Weightage Elicitation

a. SMART – Simple Multi Attribute Rating Technique.
b. SWING-SMART with Swing Weighting.
c. SMARTER – Simple Multi Attribute Rating Technique Exploiting Rank, is based on a formally justifiable weighting procedure developed by Barron and Barrett for multi-attribute utility measurement. In this method inputs or attributes are ranked first, then the weight W_i or A_{ij} is determined [6]. Edward and Baron have derived the following equation for the weights (where W_1>W_2>W_3…. Wn):

$$W_i = \frac{1}{N} \sum_{n=i}^{N} \frac{1}{n} \qquad (2)$$

It has been shown that without requiring any difficult subjective judgments (a prerequisite for SMART) the SMARTER is an improvement to SMART and performs about 98% accurately as SMART [6].

2.2.2 Methods for Value Elicitation

For value elicitation, the end points of the range of an attribute have to be first fixed. The range should be optimized for the application under consideration. Once the range of an attribute is fixed, the following methods of value elicitation can be used:

a. Direct Rating: It is most appropriate when performance levels of the attribute can be judged only by subjective measures. This value judgment is carried out by experts. In this method, first the worst and the best alternative are identified and a score of 0 and 100 are assigned respectively. The value of the remaining alternatives is then considered to reflect the strength of the preferences for one alternative over another.
b. Value Function Form Assessment: A value function of different shape can be applied to each measurable attribute considered during the IRIDM process. Value function can be obtained as a function of any parameter X, the variation of which will decide the performance level of an attribute. The form of the value function should be specified in order to describe the relation between the value of X and the S_{ijk}. The shape of the curve is decided according to the importance of parameter X within the given range. This is a preferred method for quantitative attributes

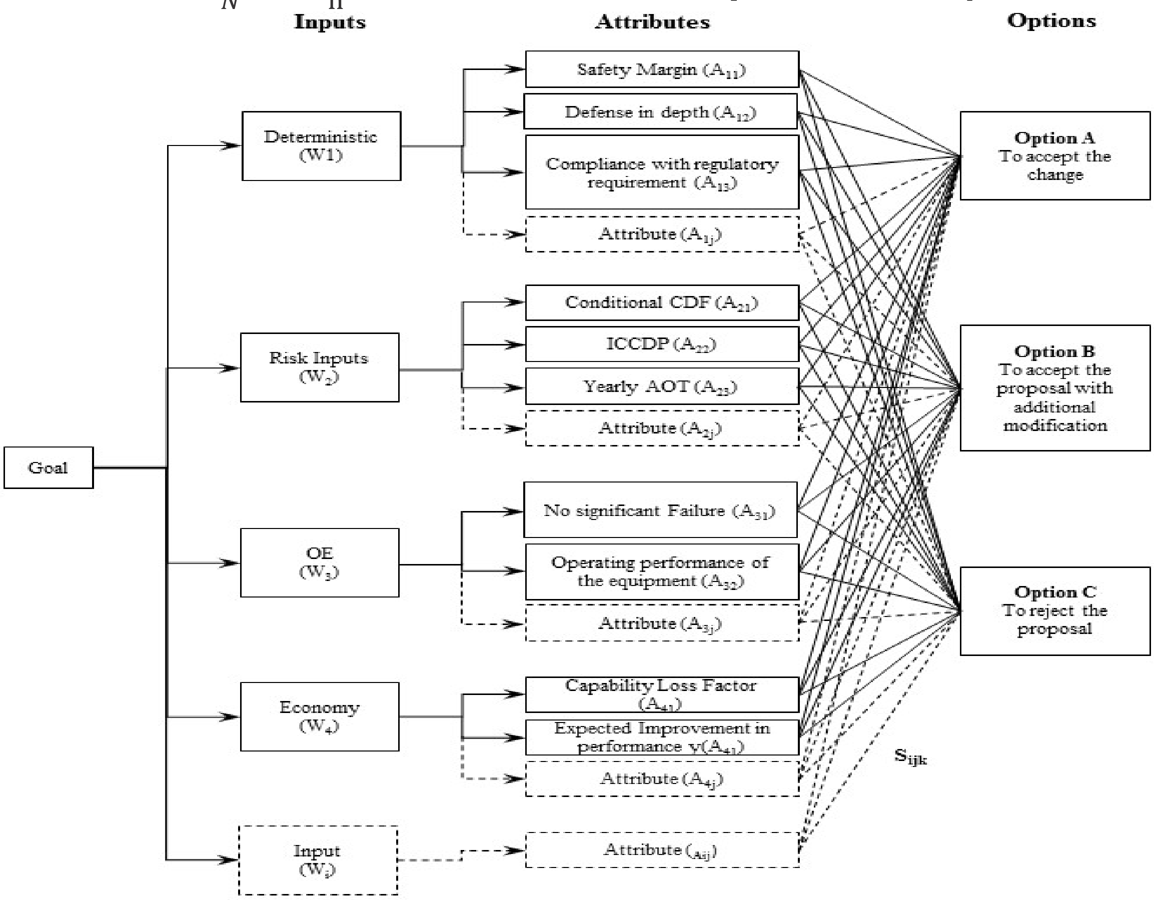

Fig. 1. Value Tree Model for Allowed Outage Time

3. Results and discussion

The IAEA has provided general guidance for making regulatory decisions using IRIDM [2, 3]. In addition, The United States Nuclear Regulatory Commission (US-NRC) has also developed guidelines [7,8] for using risk informed approach in AOT revision. However, the challenge is to develop a model that systematically gives weights to each of these IRIDM inputs to make a transparent and auditable decision. A value tree model has been developed for IRIDM of AOT based on the considerations outlined in the above references by following the steps below.

3.1 Problem Structuring for Allowed Outage Time*:*

Major decision alternatives identified for this case are: accepting the change as it is, denying the change, or accepting the change after additional modifications

Inputs and attributes to be considered for making the decision for AOT will vary from case to case. In this study, four major inputs are identified for decision making of AOTs. Deterministic assessment and probabilistic assessment are the two major inputs recognized in the literature. These two inputs are also considered in this study.

Experience gained from construction, commissioning, operation and decommissioning of NPP is termed as OE. It includes events, precursors, deviations, good practices, lessons learned and corrective actions. OE is valuable information for improving nuclear and radiological safety and hence has been identified as the third input.

It is important to assure that NPPs are competitive with respect to high availability. The factors, which directly influence availability and costs, are the outage frequency, outage duration, and resources used. Hence Economy has been considered as the fourth input.

For evaluation of the above inputs, qualitative or quantitative attributes are identified for each of them. Each attribute has to be assessed to identify the best decision option that satisfies the goal.

Attributes for Deterministic Input*:* Implementation of a proposed change should ensure that the existing regulatory requirements are complied with and adequate safety margins as envisaged are maintained. In addition to above, Defense in Depth (DID) which deals with independent multiple layers of prevention, protection, and mitigation, shall always be maintained to prevent any radiological consequences. Thus deterministic inputs for AOT are sufficiency of the safety margin, compliance to regulatory standards and adequacy of DID. As all these attributes are qualitative in nature, value elicitation can be done by direct rating.

Attributes for Probabilistic Input*:* Three risk measures are identified as attributes for the evaluation of risk impact because of extended AOT. Instantaneous Core Damage Frequency (ICDF) is the increased risk level when the component is known to be unavailable and is the first attribute. ICDF is calculated by setting the safety system down event to a true state in the Probabilistic safety assessment and recalculating the Core Damage Frequency (CDF). The second attribute identified is the cumulative (Integrated) risk over the AOT period or Incremental Conditional Core Damage Probability (ICCDP). It is the single downtime risk [4].

$$ICCDP = [ICDF\text{-}Base\ CDF] \times AOT \qquad (3)$$

The third attribute is yearly AOT risk. This is the integrated risk over the duration of repair or AOT period. If the same component is undergoing the AOT 'n' number of times in a year, the yearly AOT risk would be

$$Yearly\ AOT\ risk = n \times ICCDP \qquad (4)$$

Attributes for OE Input**:** The past performance of the safety system and events related to it must be considered while reviewing the AOT. Thus attributes identified to assess the OE input can be past significant failure of the safety system and related international events [8].

Attributes for Economy Input: The shutdowns of a plant due to conservative AOT are mostly unplanned thus may not lead to optimized resource utilization. Sometimes maintenance carried out under pressure due to short AOT may result in human error and thus also have a potential to reduce the safety of an operating NPP. Thus, major attribute that can be used to assess the economy factor is the prevention of unplanned outage and in some cases; it can also be performance improvement of the safety system due to better maintenance. Following can be various measures:

a. Prevention of unplanned outage: Expected increased plant availability or increased load factor or unplanned load reductions or Unplanned capability loss factor [9]:
b. Expected improvement in plant safety system availability/ performance or reduced rate of human error.

3.2 *Preference Elicitation for Allowed Outage Time*

Weightage Elicitation of inputs and attributes: As discussed Weightage Elicitation of inputs can be done by one of the various prioritization methods. In this study, the inputs are proposed to be weighted through SMARTER method as it is less subjective and yet easily applied and accurate. In ranking the inputs, the deterministic input is considered as the most important input followed by the probabilistic input. This is because of uncertainties present in risk models. OE is ranked third and economy as fourth. For the significance order: Deterministic (W_1) > Probabilistic (W_2) > OE (W_3) > Economy (W_4), the SMARTER method (Eq. 2) would produce the weights as follows: W_1= 0.521, W_2= 0.271, W_3= 0.146 and W_4= 0.063.

Similarly, the weightage elicitation for all the attributes can be done by various prioritization methods. SMARTER can be used to weigh the attributes for probabilistic, OE and economy inputs. Deterministic attributes can be weighed equally through direct rating since all three attributes have equal priority (see Fig. 1).

Value Elicitation for the evaluation of consequence factor: For value elicitation, the performance level of all the attributes has to be measured for each decision option. Qualitative attributes for deterministic input can be measured by direct rating. Direct rating of safety margin can be carried out by engineering judgment with respect to the compliance and consequences of exceeding the acceptable values of the corresponding safety parameters. In the case of evaluation for AOT, it can be considered enough if assumption made in final safety analysis are complied with. To assess the adequacy of DID, various elements have been identified by US NRC and the fulfillment of these can be the basis of rating [10].

Quantitative attributes, in the case of probabilistic input, can be evaluated through identification of value function. Value function can be identified as a function X given by the following equation [4]

$$X = \frac{xa - xf}{xa - xi} \qquad (5)$$

Where, *xa*= acceptable value of considerable parameter which can't be exceeded, *xi*= Initial value of parameter, *xf*= final value of parameter.

Thus different decision option can be obtained by different value of *xf*. The shape of the curve should also be specified in order to describe the relation between the X value and the S_{ijk}. For example when any changes in the lower region of the parameter X space are more important to the decision makers then the changes of the same size in the upper region the concave curve should be chosen. Acceptance criteria for these attributes are given in Table I. Attributes for OE and economy similarly can be assessed either by identification of value function or direct assessment.

Table I: Acceptance Criteria for Probabilistic Measures

Risk Measure	Risk Measure value	Acceptable action
ICDF or ΔCDF	ICDF < E-06 per reactor year.	AOT extension will be considered regardless of total CDF.
	E-06 per reactor year < ICDF < E-05 per reactor year.	AOT extension will be considered only if total CDF < E-04 per reactor year.
	ICDF > E-05 per reactor year.	AOT extension will not be considered.
ICCDP	ICCDP < E-06 per reactor year.	AOT extension is allowed.

3.3 *Evaluation of decision options*

Once the values of all attributes for each input are determined best option with the highest score can be identified by Equation (1).

3.4 Software Tool

HIerarchial PREference (HIPRE) is a software tool that can be used by decision makers for multi criteria decision analysis. It has visual graphical interface which is easy to understand (see Fig. 2). The prioritization methods available in HIPRE are based on Multi Attribute Value Theory. A decision problem is visually structured into a value tree of objectives/attributes. Each decision alternative is assessed in a performance matrix [10].

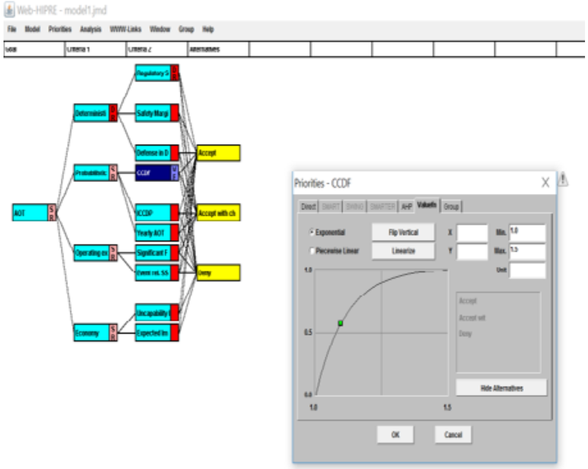

Fig. 2.Example for Value Elicitation for "Conditional Core Damage" attribute through value Function in Web-HIPRE

4. Conclusions

A systematic approach has been developed for the input evaluation and for weight assignment to each input and attribute. This approach significantly makes the IRIDM process well-structured and easier to apply. Present work puts forward a methodology of risk informed decision making for extension of Allowed outage time (AOT) of Safety System. The value tree approach complements the existing IRIDM framework proposed by IAEA. It also increases the accountability and auditability of decisions.

REFERENCES

[1] NUREG,Handbook of methods for risk based Analyzes of Technical Specification, CR141
[2] International Nuclear Safety Group, A framework for an Integrated Risk informed decision Making Process, INSAG-25.
[3] International Atomic Energy Agency, Risk informed regulation of nuclear facilities: Overview of the current status, TECDOC-1436.
[4] Mieczylaw Borysiewicz, Karol Kowal, Slawomir Potempski ,An application of the value tree analysis methodology within the integrated risk informed decision making for the nuclear facilities, Reliability Engineering and System Safety 139 (2015) 113–119.
[5] Multiple Criteria Decision Analysis E learning Helsinki University Of Technology Systems Analysis Laboratory
[6] Edwards, Barron FH ,SMARTS and SMARTER: improved methods for multi-attribute utility measurement,Organizational Behaviourand Human decision Processes , 1994
[7] United States Nuclear Regulatory Commission, An approach for using Probabilistic Risk Assessment in Risk-Informed decisions on Plant -Specific Changes to the licensing Basis, Regulatory guide 1.174.
[8] United States Nuclear Regulatory Commission. An approach for plant -specific, Risk informed decision making: Technical Specifications. Regulatory guide 1.177
[9] International Nuclear Safety Group, Guidance for optimizing nuclear power plant maintenance programmes, TECDOC1383.
[10] Mustajoki J, Hamalainen RP. Web-HIPRE: global decision support by value tree and AHP analysis. INFOR 2000; 38(3):208